Claims

1. (Previously presented) A mixed-mode fuel injector comprising:

(i) a nozzle body (5) comprising passages for fuel (FP), an inner cylindrical space for receiving a needle valve (1), and a conical surface (C) close to the tip (7) of the nozzle body for guiding a spray of fuel;

(ii) a needle valve (1), which has a converging-diverging conical head for guiding a spray of fuel and which is movable back and forth and received in said nozzle body, wherein said needle valve is at a biased closing position with its seal surface (2) being pressed against nozzle body (5) to block fuel flow, or an opening position defined by driving means through lifting the said needle valve seal surface away from nozzle body; and

(iii) a micro-variable-circular-orifice comprising a variable annular ring aperture (4) between said needle valve and said nozzle body which has means of producing hollow conical spray, and at least one conventional multijet-orifice (6) inside the said nozzle body (5) which has means of producing at least one conventional jet spray, such that fuel is dischargeable in variable sprays of hollow conical and multiple jets shapes through said micro-variable-circular-orifice and multijet-orifice by lifting said needle valve at different magnitudes.

2. (Previously presented) A mixed-mode fuel injector according claim 1, wherein the micro-variable-circular-orifice further comprises a plurality of multijet-orifices (6).

3. (Previously presented) A mixed-mode fuel injector according to claim 1 or 2, wherein the conical surface (C) has a single conical surface.

4. (Previously presented) A mixed-mode fuel injector according to claim 1 or 2, wherein the conical surface (C) is an integrated conical surface having two or more conical surfaces with different conical angles connected together.

5. (Previously presented) A mixed-mode fuel injector according to claim 1 or 2, wherein the conical surface (C) is a diverging curved surface.

6. (Previously presented) A mixed-mode fuel injector according to claim 1 or 2, wherein the needle lift for the opening position is approximately in the range of 0-300μm, the needle head diameter is approximately in the range of 0.8-3.5mm, and the angle between the centerline of the nozzle body (5) and the inner conical surface (C) at the nozzle body tip (7) is approximately in the range of 35-75 degree.

7. (Previously presented) A mixed-mode fuel injector according to claim 2, wherein the plurality of multijet-orifices (6) is on the said conical surface (C) with cross sections that are one or more of semi-circles, arcs, triangles, trapezoids or other polygons.

8. (Previously presented) A mixed-mode fuel injector according to claim 2, wherein the needle head (3) remains at least partially received within the tip (7) as the needle valve (1) is moved back and forth between the biased closing position and opening position such that when fuel is injected through the micro variable aperture (4) between the needle head and said conical surface of the nozzle body, fuel is also injected through the multijet-orifices *(6)*, the upper surface of the needle head and the conical surface serve as guiding surfaces for fuel sprays.

9. (Previously presented) A mixed-mode fuel injector according to claim 7, wherein there are about 4-20 multijet-orifices with the cross-section of semi-circles with the diameters approximately in the range of 50-300μm.

10. (Previously presented) A mixed-mode fuel injector according to claim 7, wherein there are about 4-20 multijet-orifices (6) having a cross-section other than semi-circles with the maximum dimension approximately between 50-400μm.

11. (Cancelled) A mixed-mode fuel injector according to any of *claims 2 to 10*, wherein the sizes of said multijet-orifices (6) are the same.

12. (Cancelled) A mixed-mode fuel injector according to any of *claims 2 to 10*, wherein the sizes of the multijet-orifices (6) are different depending on specific needs of atomization.

13. (Currently amended) A mixed-mode fuel injector according to *claim 2*, wherein the said multijet-orifices (6) are distributed on or under the conical surface (C) so that they can be open channels or closed channels.

14. (Previously presented) A mixed-mode fuel injector according to claim 2, has a plurality of multijet-orifices underneath the said conical surface (C), forming a sac-hole or valve-covered-orifice multi-hole type injector through blocking the circular aperture by the needle head at a predefined needle-lift range.

15. (Previously presented) A mixed-mode fuel injector according to claim 2, wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) and the needle valve is arranged within the nozzle body (5) so that, at low to medium

injection loads, fuel is mainly injected through the variable circular aperture between the needle head (3) and_conical surface (C) of nozzle body (5) by a small needle lift, thus mainly forms a conical shape spray, while at high injection loads, fuel is injected through both the variable circular aperture between the needle head and nozzle body and the multijet-orifices (6) by a larger needle lift, thus forms a mixed-mode conical-multi-jet shape spray, whereby provides different atomization desired by engine combustion at different loads.

16. (Previously presented) A mixed-mode fuel injector according to claim 2, wherein different shapes of fuel sprays are generated by changing the magnitude of lift of said needle valve (1) and the needle valve is arranged within the nozzle body (5) so that, at low to medium injection loads, fuel is mainly injected through the variable circular aperture between the needle head (3) and conical surface (C) of nozzle body by a small needle lift, thus mainly forms a conical shape spray, while at high injection loads, the needle head can completely or partially block the variable circular aperture by a large needle lift, whereby fuel is fully or mainly injected through the multijet-orifices (6), which can be open channels or closed channels depending on penetration needs, thus mainly forms conventional multi-jet sprays at high loads, whereby provides different penetration desired by engine combustion at different loads.

17. (Cancelled) A mixed-mode fuel injector according to claim 1 or 2, wherein the fuel channel between the needle valve (1) and the nozzle body (5) is of converging-diverging shape and by lifting said needle valve at different magnitudes, the minimum cross-section is at the sealing surface (2) during the early stage of fuel injection, the minimum cross- section is at said micro-variable-circular-orifice or at the sealing surface (2) during the middle stage of fuel injection, and the minimum cross-section is at the sealing surface (2) again during the late stage of fuel injection, whereby it has means of ensuring fine atomization during all fuel injection stages.

18. (Previously presented) A mixed-mode fuel injector according to claim 1 or 2, wherein the angle between the centerline of the conical surface (C) and the centerline of the nozzle body (5) is approximately 0-15 degrees, depending on an angle between a centerline of the fuel injector and a centerline of a piston in an engine cylinder.

19. (Cancelled) A mixed-mode fuel injector according to any of the preceding claims, wherein the fuel injected is one or more of diesel fuels, gasoline fuels, alternative fuels, mixtures of water and fuels, pure water or liquid exhaust cleaning additives wherein the fuel injector is a general purpose injector.

20. (Cancelled) A mixed-mode fuel injector according to claim 1, wherein the needle valve (1) is passively driven by high fuel pressure which provides said driving means.

21. (Cancelled) A mixed-mode fuel injector according to claim 1, wherein the needle valve (1) is actively driven by an actuator which provides said driving means.

22. (Cancelled) A mixed-mode fuel injector according to claim 21, wherein the actuator is a solenoid or a piezo actuator.

23. (Previously presented) A mixed-mode fuel injector, which has a micro-variable-circular-orifice (MVCO) comprising a variable annular ring aperture as in claim 1, wherein the MVCO is used as a sole orifice or in-combination with other multi-hole conventional orifice wherein fuel is injected through multiple channels in multi-jets into combustion chamber.